Adding Runtime Power Management Capabilities to Device Drivers

About me

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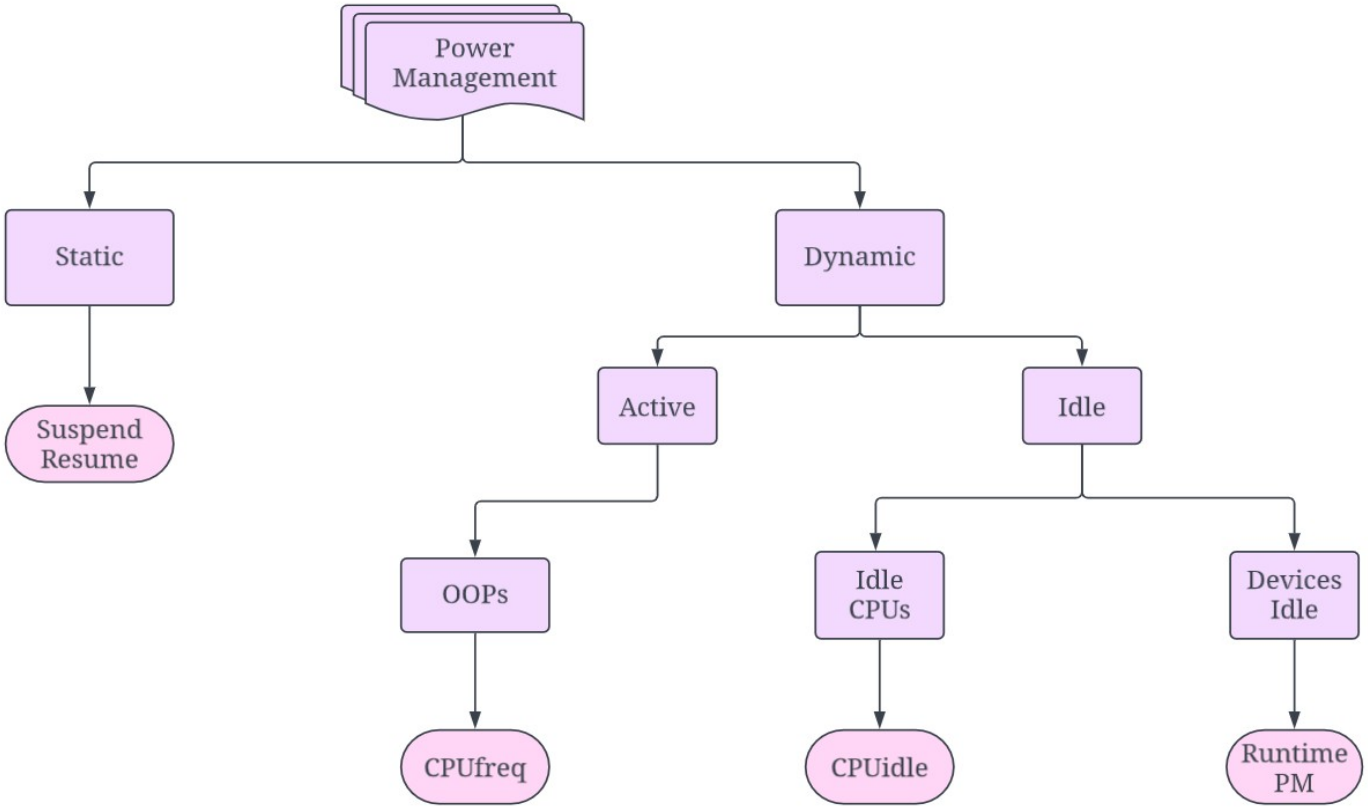
- Associate Software Engineer at Collabora
- Hardware Enablement related projects
  - RK3588 upstreaming work
  - Steam Deck Kernel Development
- KernelCI Regression tracking
- Outreachy 2020 – Sound Open Firmware project
- Started my Linux Kernel Development journey with IIO subsystem

COLLABORA

Agenda

- Power Management in Linux Kernel and Runtime PM
- Subsystem-level RPM
- Helper functions
- LTRF216A light sensor driver
- Adding RPM support to the LTRF216A driver
- Some issues and it’s solution

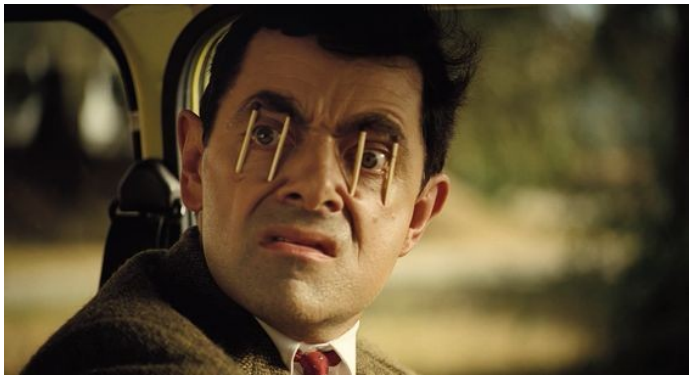
Power Management in Linux Kernel



Introduction to Kernel Power Management - by Kevin Hilman

Why was Runtime PM introduced?

- Devices were bored of being idle.
- System sleep suspends all the devices together.
- A mechanism to put individual devices to sleep was needed.
- Overall less system power consumption.



Relationship between PM Core and Runtime PM

- PM core manages the system-wide PM in Linux Kernel.
  - Synchronizes Runtime PM and system-wide PM.
  - kernel/power/main.c
- PM workqueue → pm_wq
  - Devices put their work items like suspend, resume, etc in the pm_wq.
-

```
struct dev_pm_ops {
        ...
        int (*runtime_suspend)(struct device *dev);
        int (*runtime_resume)(struct device *dev);
        int (*runtime_idle)(struct device *dev);
        ...
};
```

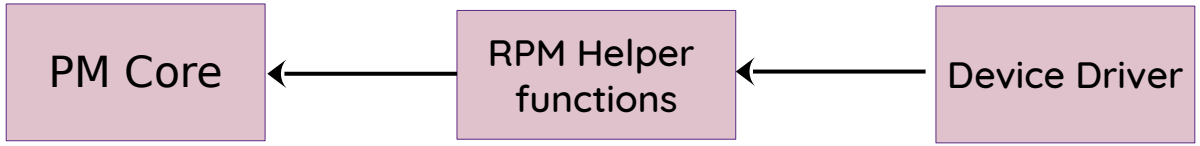
Relationship between PM Core and Runtime PM

- A set of Runtime PM fields are provided by the *power* member of the device structure.

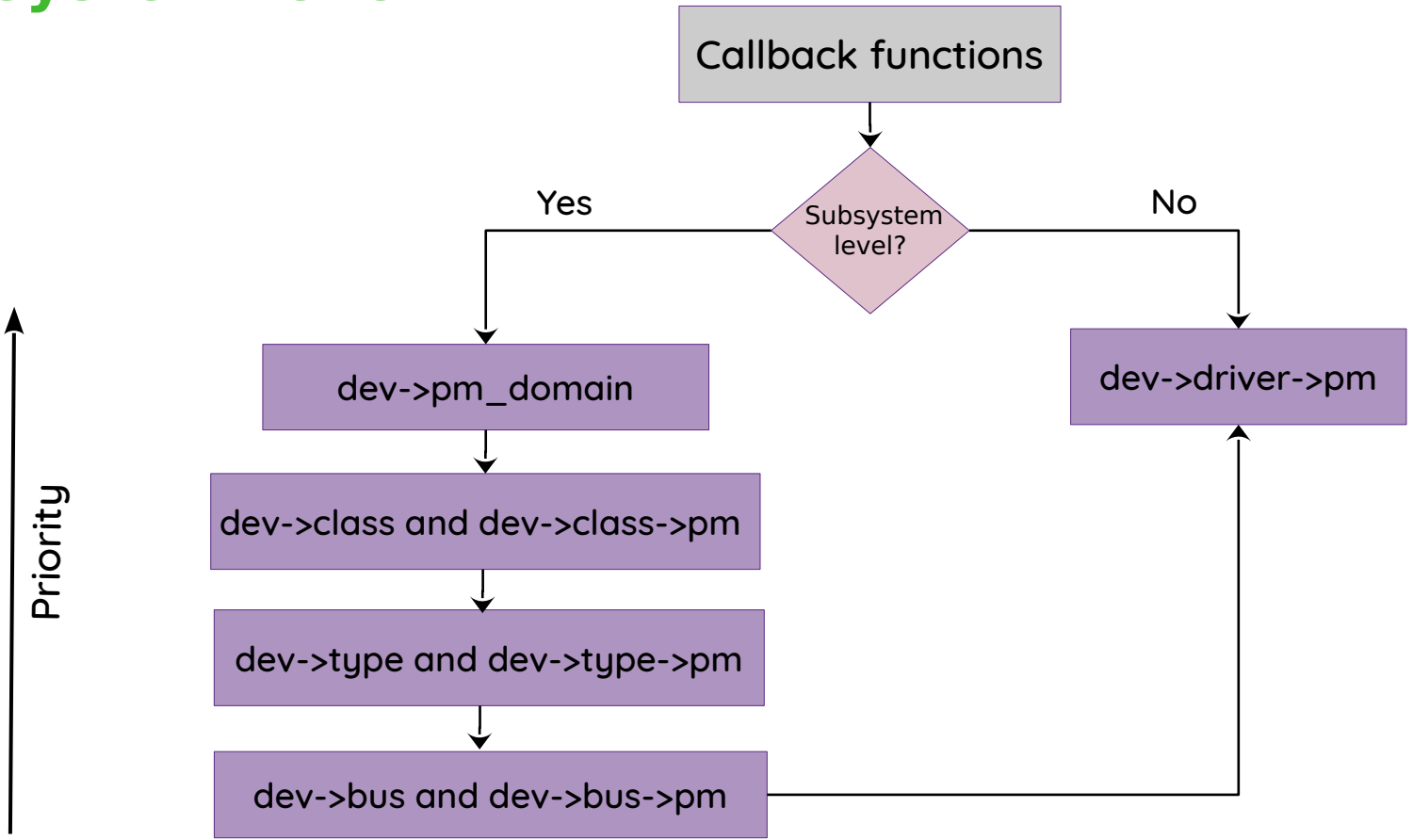
```
struct device {
    struct dev_pm_info power;
}
```

```
power.runtime_status
power.use_autosuspend
power.last_busy
power.usage_count
power.ignore_children
power.deferred_resume
...
```

- Helper functions defined in drivers/base/power/runtime.c carries out Runtime PM operations with the help of PM core.



Subsystem-level RPM



Subsystem-level Runtime PM

```
static struct bus_type ac97_bus_type = {
        ....
        .pm             = &ac97_pm,
        .probe          = ac97_bus_probe,
        .remove         = ac97_bus_remove,
};
```

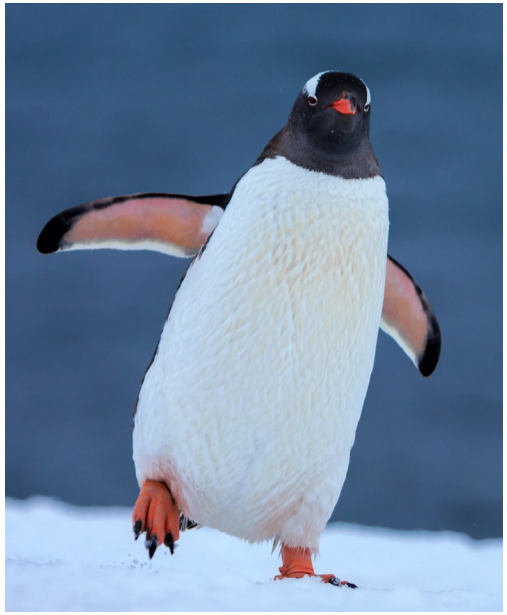
```
static const struct dev_pm_ops ac97_pm = {
        ....
        SET_RUNTIME_PM_OPS(
                ac97_pm_runtime_suspend,
                ac97_pm_runtime_resume,
                NULL)
```

```
static int ac97_pm_runtime_suspend(struct device *dev)
{
        struct ac97_codec_device *codec = to_ac97_device(dev);
        int ret = pm_generic_runtime_suspend(dev);     // calls runtime_suspend for the device

        if (ret == 0 && dev->driver) {                 // disables the codec clock
                if (pm_runtime_is_irq_safe(dev))
                        clk_disable(codec->clk);
                else
                        clk_disable_unprepare(codec->clk);
```

sound/ac97/bus.c

Parent-Child Relationship

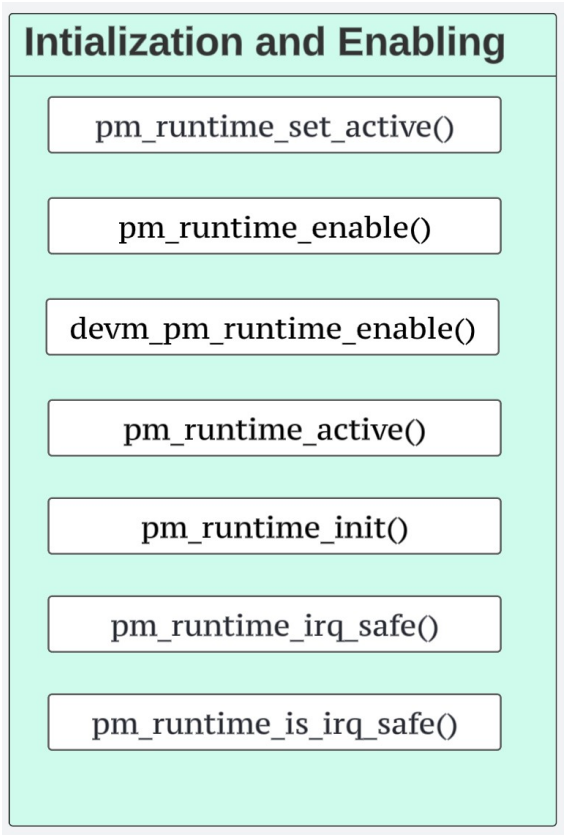


pm_suspend_ignore_children()

power.ignore_children = true

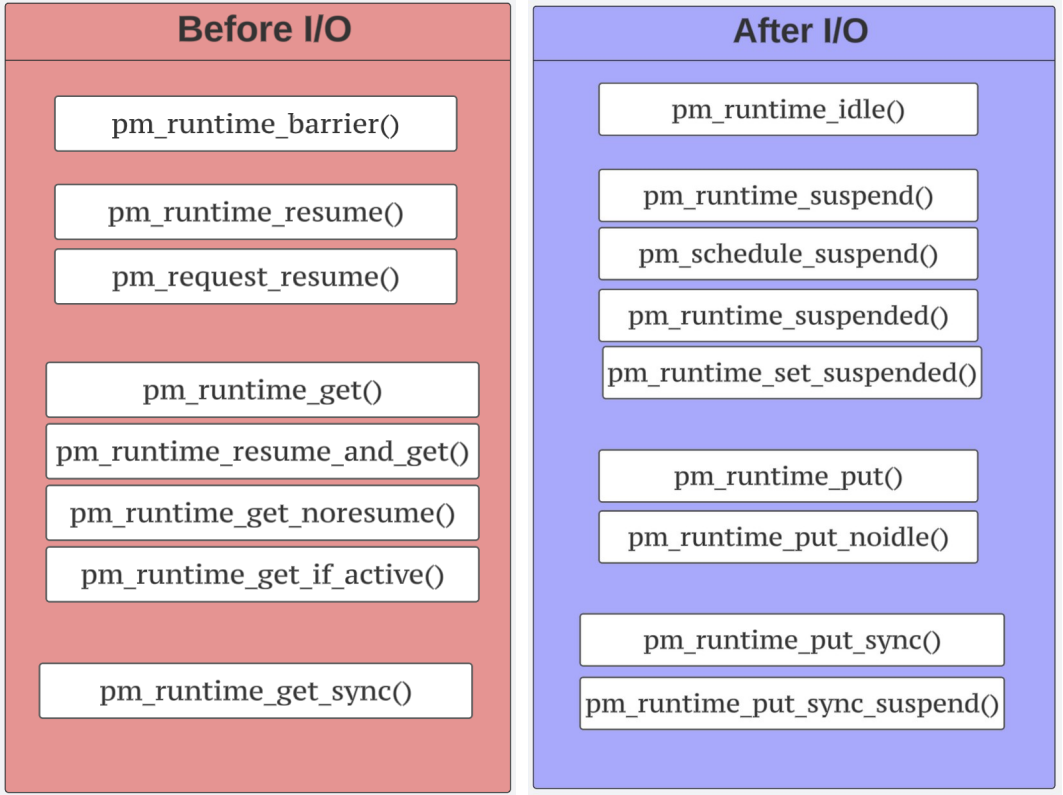
Helper functions – Initialization and Enabling

- Initial runtime PM status of all the devices is ‘suspended’
  - That might not be it’s true physical state.
- devm_pm_runtime_enable() automatically handles the disabling of the Runtime PM.
- Callbacks can be executed in atomic context with interrupts disabled using pm_runtime_irq_safe()
  - It will set the power.irq_safe flag
  - It will also not let the parent device being runtime-suspended.



Helper functions – Before and After I/O

- There can be multiple users of the device.
- Reference counting helps to keep a track of the device usage requests.
  - _get_() ⟶ power.usage_count += 1
  - _put_() ⟶ power.usage_count -= 1
- pm_runtime_get() increments the usage_count even on returning an error.
- Want to wait for the power state transition to complete before executing the next code block?
  - Use _sync_() Runtime PM helper functions.

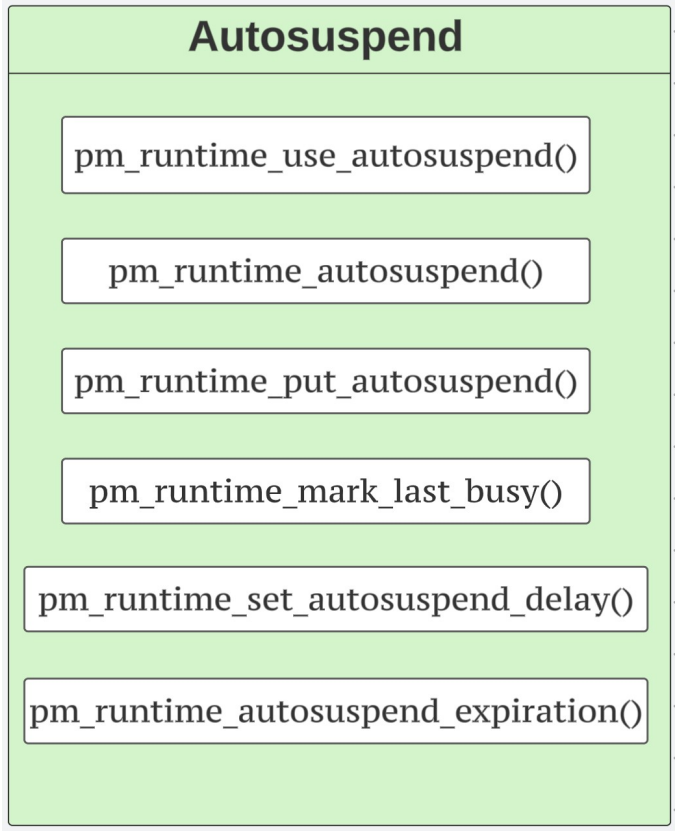


Helper functions - Autosuspend

- Imagine you have a device which does I/O operation every 1 sec.
- A lot of time and energy is wasted.
- Add an inactivity period with the help of autosuspend delay.
- Deffering the suspend until inactivity period has elapsed.

Helper functions - Autosuspend

- Inactivity period is set using the pm_runtime_set_autosuspend_delay(dev, delay)
- Drivers need to keep a record of their last I/O operation time.
  - pm_runtime_mark_last_busy() updates the power.last_busy field.
- Inactivity period can also be handled through sysfs.
  - `/sys/devices/.../power/autosuspend_delay_ms`
- Race Conditions?



Helper functions – Removal and some more...

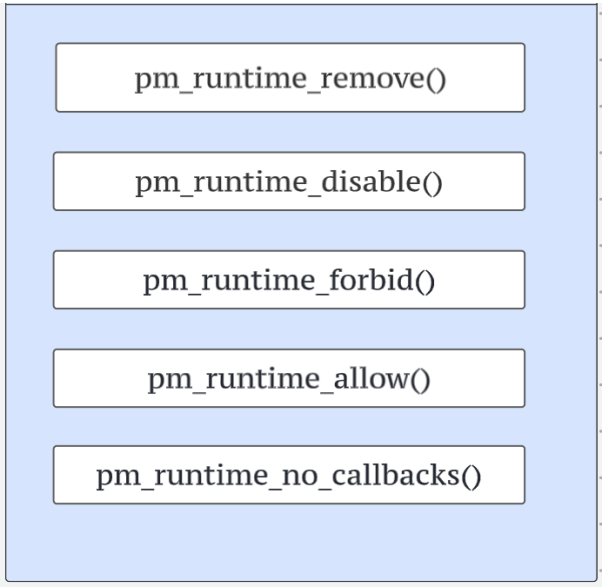
- All the pending PM operations are completed/cancelled while disabling the device.
- pm_runtime_remove() will disable the runtime PM and unregister device from Runtime PM framework.
- pm_runtime_forbid()

```
echo “on” > /sys/devices/.../power/control
```

- pm_runtime_allow()

```
echo “auto” > /sys/devices/.../power/control
```

- pm_runtime_no_callbacks() will delete the runtime PM attributes.



https://docs.kernel.org/power/runtime_pm.html

LTRF216A light sensor driver

- I2C Ambient Light Sensor (ALS)
- ALS DATA is the digital representation of ambient light level stored in the registers regardless of light sources.
  - Raw value
- Lux_calc is a meaningful representation of the actual light intensity in a specific environment.
  - Processed value
- Supports multiple integration time.
  - 25ms, 50ms, 100ms, 200ms and 400ms.

LTRF216A light sensor driver

```
static int ltrf216a_probe(struct i2c_client *client)
{
        ...
        indio_dev = devm_iio_device_alloc(&client->dev, sizeof(*data));

        data = iio_priv(indio_dev);
        data->regmap = devm_regmap_init_i2c(client, &ltrf216a_regmap_config);

        i2c_set_clientdata(client, indio_dev);

        indio_dev->info = &ltrf216a_info;
        indio_dev->name = "ltrf216a";
        indio_dev->channels = ltrf216a_channels;
        indio_dev->num_channels = ARRAY_SIZE(ltrf216a_channels);

        /* reset sensor, chip fails to respond to this, so ignore any errors */
        ltrf216a_reset(indio_dev);

        ret = ltrf216a_enable(indio_dev);

        data->int_time = 100000;
        data->int_time_fac = 100;
        data->als_gain_fac = 3;

        return devm_iio_device_register(&client->dev, indio_dev);
}
```

```
static const struct iio_info ltrf216a_info = {
        .read_raw = ltrf216a_read_raw,
        .write_raw = ltrf216a_write_raw,
        .read_avail = ltrf216a_read_available,
};
```

drivers/iio/light/ltrf216a.c

LTRF216A light sensor driver

```
static int ltrf216a_read_raw(struct iio_dev *indio_dev,...)
{
        struct ltrf216a_data *data = iio_priv(indio_dev);
        int ret;

        switch (mask) {
        case IIO_CHAN_INFO_RAW:
                mutex_lock(&data->lock);
                ret = ltrf216a_read_data(data, LTRF216A_ALS_DATA_0);
                mutex_unlock(&data->lock);
                *val = ret;
                return IIO_VAL_INT;
        case IIO_CHAN_INFO_PROCESSED:
                mutex_lock(&data->lock);
                ret = ltrf216a_get_lux(data);
                mutex_unlock(&data->lock);
                *val = ret;
                return IIO_VAL_INT;
        case IIO_CHAN_INFO_INT_TIME:
                mutex_lock(&data->lock);
                ret = ltrf216a_get_int_time(data, val, val2);
                mutex_unlock(&data->lock);
                return ret;
        default:
                return -EINVAL;
        }
}
```

```
static int ltrf216a_write_raw(struct iio_dev *indio_dev,...)
{       ...
        switch (mask) {
        case IIO_CHAN_INFO_INT_TIME:
                mutex_lock(&data->lock);
                ret = ltrf216a_set_int_time(data, val2);
                mutex_unlock(&data->lock);
                return ret;
        ...
}
```

```
static int ltrf216a_read_available(struct iio_dev *indio_dev,...)
{
        switch (mask) {
        case IIO_CHAN_INFO_INT_TIME:
                *length = ARRAY_SIZE(ltrf216a_int_time_available)*2;
                *vals = (const int *)ltrf216a_int_time_available;
                *type = IIO_VAL_INT_PLUS_MICRO;
                return IIO_AVAIL_LIST;
        ...
}
```

LTRF216A light sensor driver

```
static int ltrf216a_probe(struct i2c_client *client)
{
        ...
        indio_dev = devm_iio_device_alloc(&client->dev, sizeof(*data));

        data = iio_priv(indio_dev);
        data->regmap = devm_regmap_init_i2c(client, &ltrf216a_regmap_config);

        i2c_set_clientdata(client, indio_dev);

        indio_dev->info = &ltrf216a_info;
        indio_dev->name = "ltrf216a";
        indio_dev->channels = ltrf216a_channels;
        indio_dev->num_channels = ARRAY_SIZE(ltrf216a_channels);

        /* reset sensor, chip fails to respond to this, so ignore any errors */
        ltrf216a_reset(indio_dev);

        ret = ltrf216a_enable(indio_dev);

        data->int_time = 100000;
        data->int_time_fac = 100;
        data->als_gain_fac = 3;

        return devm_iio_device_register(&client->dev, indio_dev);
}
```

```
static const struct iio_chan_spec ltrf216a_channels[] = {
        {
                .type = IIO_LIGHT,
                .info_mask_separate =
                        BIT(IIO_CHAN_INFO_RAW) |
                        BIT(IIO_CHAN_INFO_PROCESSED) |
                        BIT(IIO_CHAN_INFO_INT_TIME),
                .info_mask_separate_available =
                        BIT(IIO_CHAN_INFO_INT_TIME),
        },
};
```

LTRF216A light sensor driver

```
(B+)(root@steamdeck ~)# ls -l /sys/bus/iio/devices/iio\:device0/
total 0
-rw-r--r-- 1 root root 4096 Jun 21 03:24 in_illuminance_input
-rw-r--r-- 1 root root 4096 Jun 21 03:24 in_illuminance_integration_time
-r--r--r-- 1 root root 4096 Jun 21 03:24 in_illuminance_integration_time_available
-rw-r--r-- 1 root root 4096 Jun 21 03:24 in_illuminance_raw
-r--r--r-- 1 root root 4096 Jun 21 03:24 name
drwxr-xr-x 2 root root    0 Jun 21 03:24 power
lrwxrwxrwx 1 root root    0 Jun 21 03:24 subsystem -> ../../../../../../bus/iio
-rw-r--r-- 1 root root 4096 Jun 21 03:24 uevent


(B+)(root@steamdeck ~)# cat /sys/bus/iio/devices/iio\:device0/in_illuminance_integration_time
0.100000

(B+)(root@steamdeck ~)# cat /sys/bus/iio/devices/iio\:device0/in_illuminance_integration_time_available
0.400000 0.200000 0.100000 0.050000 0.025000

(B+)(root@steamdeck ~)# cat /sys/bus/iio/devices/iio\:device0/in_illuminance_raw
90

(B+)(root@steamdeck ~)# cat /sys/bus/iio/devices/iio\:device0/in_illuminance_input
13.350000000
```

Adding RPM support to LTRF216A light sensor driver

```
static int ltrf216a_probe(struct i2c_client *client)
{
        ...
        indio_dev->info = &ltrf216a_info;
        indio_dev->name = "ltrf216a";
        indio_dev->channels = ltrf216a_channels;
        indio_dev->num_channels = ARRAY_SIZE(ltrf216a_channels);
        indio_dev->modes = INDIO_DIRECT_MODE;

        ret = pm_runtime_set_active(&client->dev);
        if (ret)
                return ret;

        ltrf216a_reset(indio_dev);

        ret = ltrf216a_enable(indio_dev);
        if (ret)
                return ret;

        ret = devm_add_action_or_reset(&client->dev, ltrf216a_cleanup,
                                       indio_dev);
        ....
```

```
   ret = devm_pm_runtime_enable(&client->dev);
   if (ret)
        return dev_err_probe(&client->dev, ret,
                             "failed to enable runtime PM\n");

   pm_runtime_set_autosuspend_delay(&client->dev, 1000);
   pm_runtime_use_autosuspend(&client->dev);

   data->int_time = 100000;
   data->int_time_fac = 100;
   data->als_gain_fac = 3;

   return devm_iio_device_register(&client->dev, indio_dev);
}
```

Adding RPM support to LTRF216A light sensor driver

```
static int ltrf216a_read_raw(struct iio_dev *indio_dev,...)
{
        switch (mask) {
        case IIO_CHAN_INFO_RAW:
                ret = ltrf216a_set_power_state(data, true);
                if (ret)
                        return ret;
                mutex_lock(&data->lock);
                ret = ltrf216a_read_data(data, LTRF216A_ALS_DATA_0);
                mutex_unlock(&data->lock);
                ltrf216a_set_power_state(data, false);
                if (ret < 0)
                        return ret;
                *val = ret;
                return IIO_VAL_INT;
        case IIO_CHAN_INFO_PROCESSED:
                mutex_lock(&data->lock);
                ret = ltrf216a_get_lux(data);
                mutex_unlock(&data->lock);
                if (ret < 0)
                        return ret;
                *val = ret;
                return IIO_VAL_INT;
        case IIO_CHAN_INFO_INT_TIME:
                mutex_lock(&data->lock);
                ret = ltrf216a_get_int_time(data, val, val2);
                mutex_unlock(&data->lock);
       ....
```

```
static int ltrf216a_get_lux(struct ltrf216a_data *data)
{
        ...
        ret = ltrf216a_set_power_state(data, true);
        if (ret)
                return ret;

        greendata = ltrf216a_read_data(data, LTRF216A_ALS_DATA_0);
        if (greendata < 0)
                return greendata;

        ltrf216a_set_power_state(data, false);

        lux = greendata * 45 * LTRF216A_WIN_FAC * 100;
        div = data->als_gain_fac * data->int_time_fac * 100;

        return div_u64(lux, div);
}
```

Adding RPM support to LTRF216A light sensor driver

```
int ltrf216a_set_power_state(struct ltrf216a_data *data, bool on)
{
     struct device *dev = &data->client->dev;
     int ret = 0;

     if (on) {
          ret = pm_runtime_resume_and_get(dev);
          if (ret) {
              dev_err(dev, "failed to resume runtime PM: %d\n", ret);
              return ret;
          }
     } else {
              pm_runtime_mark_last_busy(dev);
              pm_runtime_put_autosuspend(dev);
     }

     return ret;
}
```

Adding RPM support to LTRF216A light sensor driver

```
static int ltrf216a_runtime_suspend(struct device *dev)
{
        ...
        ret = ltrf216a_disable(indio_dev);
        if (ret)
                return ret;
        ...
}

static int ltrf216a_runtime_resume(struct device *dev)
{
        ...
        ret = ltrf216a_enable(indio_dev);
        if (ret)
                goto cache_only;

        return 0;
        ...
}
```

```
static DEFINE_RUNTIME_DEV_PM_OPS(ltrf216a_pm_ops, ltrf216a_runtime_suspend,
                                 ltrf216a_runtime_resume, NULL);


static struct i2c_driver ltrf216a_driver = {
        .driver = {
                .name = "ltrf216a",
                .pm = pm_ptr(&ltrf216a_pm_ops),
                .of_match_table = ltrf216a_of_match,
        },
        .probe_new = ltrf216a_probe,
        .id_table = ltrf216a_id,
};
module_i2c_driver(ltrf216a_driver);
```

```
(B+)(root@steamdeck ~)# ls -l /sys/bus/iio/devices/iio\:device0/power/
total 0
-rw-r--r-- 1 root root 4096 Jun 21 03:26 autosuspend_delay_ms
-rw-r--r-- 1 root root 4096 Jun 21 03:26 control
-r--r--r-- 1 root root 4096 Jun 21 03:25 runtime_active_time
-r--r--r-- 1 root root 4096 Jun 21 03:25 runtime_status
-r--r--r-- 1 root root 4096 Jun 21 03:25 runtime_suspended_time
(B+)(root@steamdeck ~)#
```

Powertop

```
PowerTOP 2.15     Overview   Idle stats   Frequency stats   Device stats   Tunables   WakeUp

The battery reports a discharge rate of 4.76 W
The energy consumed was 93.8 J

             Usage     Device name
             19.3%       CPU misc
             19.3%       CPU core
            100.0%       USB device: xHCI Host Controller
            100.0%       USB device: Steam Deck Controller (Valve Software)
              5.5%       Display backlight
              0.0%       USB device: xHCI Host Controller
            100.0%       PCI Device: Advanced Micro Devices, Inc. [AMD] VanGogh Data Fabric; Function 1
            100.0%       PCI Device: Advanced Micro Devices, Inc. [AMD] Renoir PCIe Dummy Host Bridge
            100.0%       PCI Device: Advanced Micro Devices, Inc. [AMD] Renoir PCIe Dummy Host Bridge
            100.0%       PCI Device: Advanced Micro Devices, Inc. [AMD] VanGogh PCIe GPP Bridge
            100.0%       PCI Device: Phison Electronics Corporation PS5013 E13 NVMe Controller
            100.0%       PCI Device: Advanced Micro Devices, Inc. [AMD] VanGogh Data Fabric; Function 5
            100.0%       PCI Device: O2 Micro, Inc. SD/MMC Card Reader Controller
            100.0%       Radio device: rtw_8822ce
            100.0%       PCI Device: Advanced Micro Devices, Inc. [AMD] VanGogh PCIe GPP Bridge
            100.0%       PCI Device: Advanced Micro Devices, Inc. [AMD] VanGogh USB2
```

```
(B+)(root@steamdeck ~)# ls -l /sys/bus/iio/devices/iio\:device0/power/*time
-r--r--r-- 1 root root 4096 Jun 21 03:25 /sys/bus/iio/devices/iio:device0/power/runtime_active_time
-r--r--r-- 1 root root 4096 Jun 21 03:25 /sys/bus/iio/devices/iio:device0/power/runtime_suspended_time
```

What issues you might face?

- Loss of data
  - Registers will be reset to their initial values after resuming the device.
  - Drivers need to implement a way to restore the data before suspending the device.
- Not all devices work independently
  - The Generic Power Domain (genpd) framework.
  - Genpd facilitates coordinated power management at both the device level and subsystem level.

Special Thanks

Dmitrii Osipenko

Sebastian Reichel

Thank you

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